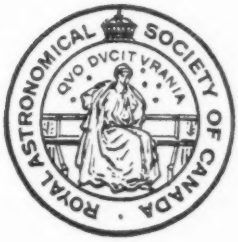
THE JOURNAL OF THE ROYAL ASTRONOMICAL SOCIETY OF CANADA

DEVOTED TO THE ADVANCEMENT OF ASTRONOMY AND ALLIED SCIENCES



AUGUST 1961

Volume 55, Number 4 Whole Number 451

WILLIAM R. HOSSACK

1927 - 1961

It is with deep regret that we announce the death of Dr. William R. Hossack, National Treasurer of the Royal Astronomical Society of Canada, in an accident near Ottawa, Ont., on July 10, 1961. An obituary will appear in the next issue of the JOURNAL.

PRINTED IN CANADA
BY THE UNIVERSITY OF TORONTO PRESS

4

A

6

1

XU

THE JOURNAL OF THE
ROYAL ASTRONOMICAL SOCIETY
OF CANADA

Vol. 55, No. 4 AUGUST 1961 Whole No. 451

GALACTIC STRUCTURE AT OPTICAL AND RADIO WAVE-LENGTHS*

By Maarten Schmidt
Mount Wilson and Palomar Observatories, Carnegie Institution of Washington, California Institute of Technology, Pasadena, California

The study of the structure of our Galaxy has greatly profited by data obtained at radio wave-lengths and my aim is to show how, through both optical and radio studies, our knowledge of galactic structure has increased during the last ten years.

In studying our Galaxy we may ask ourselves three questions. First: what is the distribution of objects of different type, such as B-type stars, globular clusters, interstellar gas clouds, and so on? Second: how is the Galaxy kept together? And third: how will it change with time? The three subjects involved are those of galactic structure, dynamics and evolution. We shall be mainly concerned with galactic structure here, and I have limited myself to large-scale structural features of the Galaxy. I shall consider briefly at the end some of the results of interest in the dynamics and the evolution of the Galaxy.

By way of introduction I should like to outline briefly our knowledge of galactic structure as it was nine years ago. Figure 1 shows the Galaxy's nearest neighbour of comparable size, the Andromeda Galaxy. The tilt of the equatorial plane of the galaxy to the line of sight is around 14°. Figure 2 gives a schematic view of our own Galaxy, as it would be seen edge-on. Most of the stars are concentrated both in the plane of symmetry, and toward the centre of the Galaxy, and are contained in a discus-like volume with axial ratio about 1 to 10. Globular clusters and other so-called high-velocity objects have a more spherical distribution, and

*Address given on the occasion of the opening of the Dominion Radio Astrophysical Observatory, Penticton, B.C., June 21, 1960.

FIG. 1—The Andromeda Galaxy.

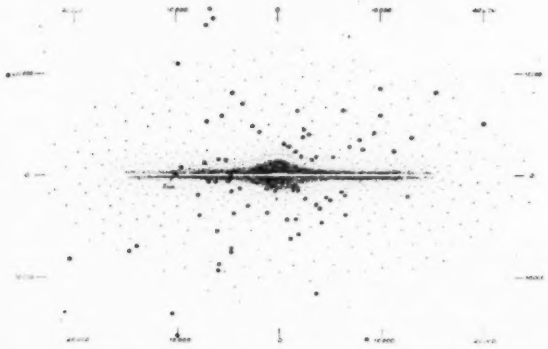


FIG. 2—Schematic view of the Galaxy, edge-on. Distances in parsecs; heavy dots are globular clusters.

are concentrated toward the centre only. On the other hand bright young stars, and clouds of gas and dust are concentrated in the galactic plane, thus forming an extremely flat, extended layer. The sun is located in this plane, about 10 kiloparsecs from the centre. The strong absorption

due to the dust in the layer is seen in the picture (figure 3) of the galaxy

FIG. 3—The galaxy NGC 891.

NGC 891, which is seen edge-on. Unfortunately, the sun being in the galactic plane, we see our own Galaxy edge-on, and the dust layer is clearly seen on the photograph of the Milky Way (figure 4), which was made with a wide-angle camera. The absorption on the average amounts to around 1 magnitude per kiloparsec, so that in looking towards the centre of our Galaxy we may expect an attenuation of 10^4. Due to this strong absorption, studies of the distribution of stars have in general not reached out any further than a few kiloparsecs. Our knowledge of galactic structure before 1950 is probably best characterized by Oort's finding, in 1938, that the density of stars increases steadily toward the centre of the Galaxy.

The existence of spiral structure in the Galaxy had been suspected for a long time but it was not until 1951 that the first evidence was produced by Morgan, Sharpless and Osterbrock from a study of hydrogen emission regions (figure 5). Baade had shown that in the Andromeda galaxy these emission regions nicely outline the spiral arms, and the authors concluded that two, possibly three, arms were indicated by the emission regions.

At this point I should like to turn to radio astronomy, because it

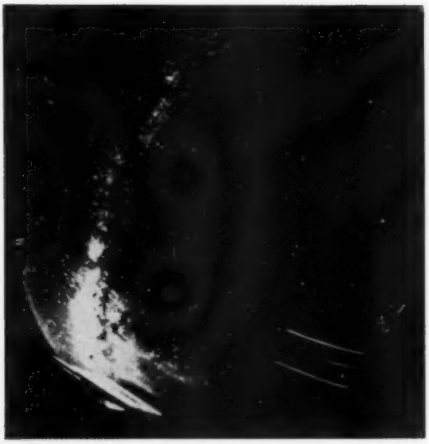


FIG. 4—Wide-angle camera photograph of Milky Way showing dust-layer.

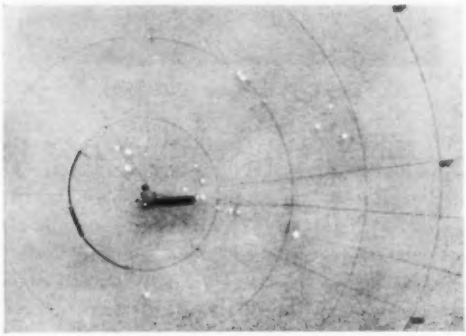


FIG. 5—A photograph of the Morgan-Sharpless-Osterbrock model of the Galaxy in the sun's vicinity, showing the spatial distribution of the hydrogen-emission regions that outline the spiral arms. (Yerkes Observatory photograph.)

started to play an important role in the present field, when in the same year, 1951, the 21-cm. line radiation was detected. The impact of the 21-cm. work was considerable: within a year after the detection of the line a spiral arm was mapped halfway around the Galaxy; in 1955 structure had been completely unwrapped in the northern hemisphere and now we have it almost all over the Galaxy. The spectral line at 21-cm. wave-length is emitted during a transition between two hyperfine

structure levels in the hydrogen atom. The intrinsic line-width is unobservably small, the frequency is known accurately. Aspects of great importance are the following: First, we are observing the ground state of hydrogen, optically unobservable, hydrogen probably being the most abundant element in the universe. Second, interstellar space is transparent at this wave-length, except for self-absorption. Third, any shift or widening of the line in frequency is interpreted—through the Doppler effect—in terms of radial motion of the emitting hydrogen atoms.

Let us now assume that all hydrogen clouds move in circular orbits around the centre, and also that we know the velocity of rotation in circular orbits (called circular velocity) in the galactic plane at all distances from the centre. Part of the circular-velocity curve, as shown in figure 6 could be determined directly from observations at 21-cm.

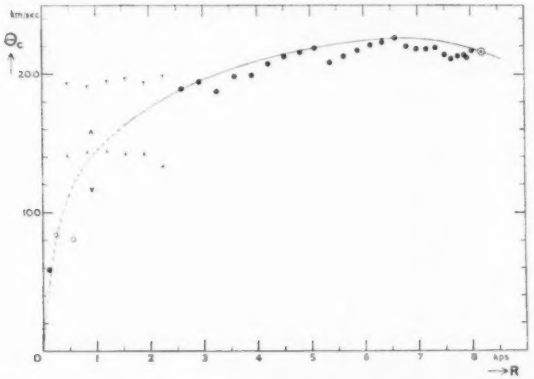


FIG. 6—Circular velocity curve of motion of hydrogen clouds with distance from galactic centre.

wave-length. Figure 7 may serve to explain which effects on the observed radial velocities may be expected if everything moves in circular orbits, including the sun and the hydrogen clouds. It turns out that for a given direction the radial velocity will depend only on the distance to the galactic centre. Thus for each radial velocity we can specify the corresponding distance to the centre and this again corresponds to one or two values of the distance to the sun. The ambiguity in distance occurs for objects in the interior regions of the Galaxy. Profiles at various galactic longitudes are shown in figure 8. We see that the line is always widened, even in the direction to the centre and the anticentre, where we would not expect any frequency shifts on the assumption of purely circular

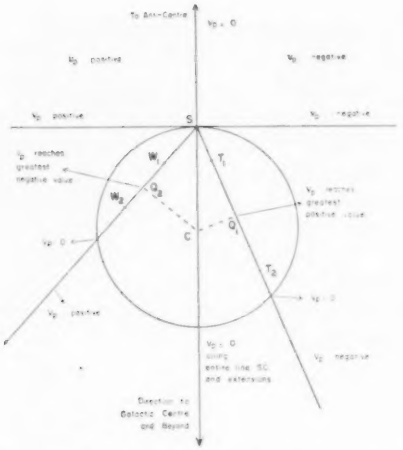


FIG. 7—Radial-velocity effects of motion in circular orbits.

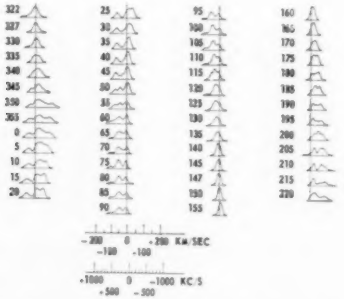


FIG. 8—21-cm. line profiles at various longitudes.

motions. This indicates that clouds may have non-circular orbits, and if we assume that the velocity deviations are random, the dispersion of velocities turns out to be about 5 to 8 km./sec., quite small compared to the circular velocity of over 200 km./sec. In many directions we see more than one peak, such as at longitude 80°, where we see three peaks. These then must be due to concentrations of hydrogen at three different distances. Figure 9 shows a sketch of part of the structure one obtains by studying the line profiles at different galactic longitudes. In the inner parts of the Galaxy, where a distance to the galactic centre corresponds to two positions on the line-of-sight, we need another distance indicator

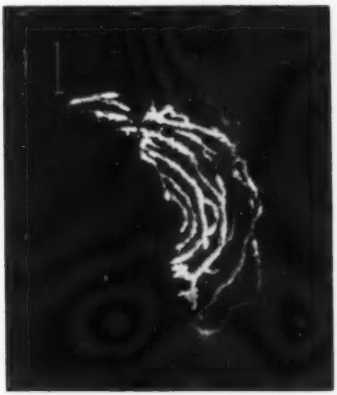


FIG. 9—Sketch of the distribution of neutral hydrogen in the northern part of the Galaxy.

to separate the two contributions. This has been found in the angular width, which for the contribution from the far point should be smaller than the one from the near point.

In judging how well the structure is determined from the observations, one should keep in mind that if large-scale deviations from circular motion exist, we shall find an incorrect distance, because the local circular velocity plus the deviations of unknown magnitude simulates, and cannot be distinguished from, a purely circular velocity at some other distance. A clear example of non-circular motion is seen in line profiles near the galactic centre (figure 10), where circular motion would not give rise to any appreciable radial velocities. The peak seen here is due to an expanding arm at only 3 kpc. from the centre of the Galaxy, which approaches us with a velocity of 53 km./sec. I shall not discuss the fascinating information we now have on the structure and the motions in the very central regions of our Galaxy. It seems quite likely that deviations from circular motion as large as the one just mentioned occur only in the central parts of the Galaxy.

Figure 11 shows a 21-cm. absorption profile taken in the direction of the Crab nebula, that is the radio source Taurus A. The source is located in a direction only 5° from the direction of the anticentre, at a distance of about 1 kpc. Thus from differential galactic rotation one would expect a shift of the profile of around 1 km./sec. We see, however, that the absorbing material, hydrogen clouds between the Crab nebula and ourselves, has a mean velocity of approach of 8 km./sec. Statistically this

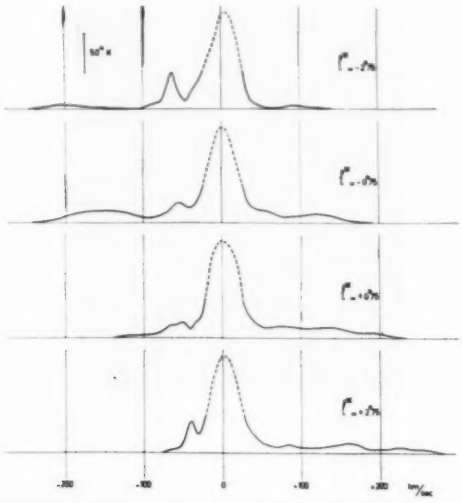


FIG. 10—Line profiles near galactic centre. Longitudes on new system counted from the direction of the centre as zero-point. The principal maximum, which is almost entirely due to hydrogen outside the central region, is indicated by a dotted curve.

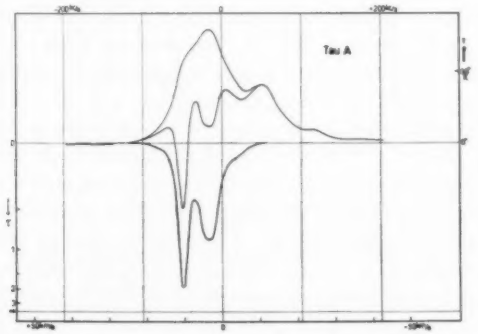


FIG. 11—21-cm. absorption profile in direction of Crab Nebula.

may be poorly established because the effective angular resolution of the absorption profile is only 5′, while the survey described was carried out with a 2° beam, thus averaging over many more clouds. The emission profile seems to centre fairly well around the rest frequency, but it shows an extension to at least −40 km./sec. The intensity here is quite low, and presumably is due to a rather tenuous medium, which may not affect

the overall hydrogen structure very much. Yet this feature is extremely interesting. Other evidence of non-circular motions comes from peaks in line profiles indicating a recession in a direction where we would expect approach. The combined evidence leads to the impression that large-scale velocity deviations may amount to 5 km./sec., and possibly double or triple this amount in some cases. Optically, a comparison of the radial velocities of stars with those of interstellar gas as found from the interstellar absorption lines may show velocity anomalies, and we shall discuss such a case a little later.

Another uncertainty in the structure obtained is due to the rotation curve already mentioned. An important part has been determined from 21-cm. observations, but one first has to adopt the values of certain fundamental parameters: the circular velocity at the sun's distance from the centre, the rate of change with distance, and the sun's distance from the centre of the Galaxy. These parameters have to be determined from optical observations, although the radio data furnish information about a certain combination of the parameters. The somewhat controversial matter regarding the value of these fundamental parameters has not been resolved as yet. If the values of the parameters used are in error, and I think they are, the main effect on the hydrogen distribution will be a scale error and a slight distortion.

Figure 12 shows the distribution of hydrogen over most of the Galaxy. We generally call the stretches of increased hydrogen density spiral arms, but without the optical pictures of extragalactic nebulae in our

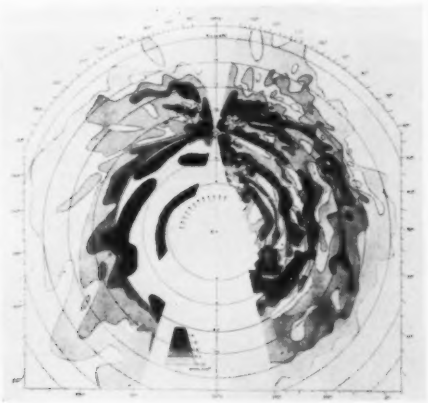


FIG. 12—Distribution of neutral hydrogen in the Galaxy. The maximum densities in the z-direction are projected on the galactic plane, and contours are drawn through the points.

minds, they might not have been called 'spiral' arms. Figure 13 shows M81, an Sb-type galaxy, and figure 14 shows M101, an Sc-galaxy. In all cases there are breaks in the arms and sometimes connections between different arms. Remembering that the hydrogen structure in the Galaxy is probably less irregular in reality than our picture of it, due to the

FIG. 13—M81, an Sb galaxy.

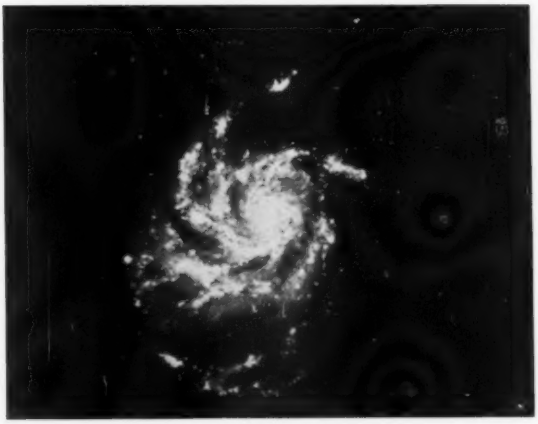


FIG. 14—M101, an Sc galaxy.

effect of non-circular motions, we may conclude that the Galaxy's hydrogen structure resembles ordinary optical spiral structure as we see it in other galaxies.

Let us now see what optical evidence of structure in the Galaxy has accumulated since 1951. For common stars no other regular or semi-regular structure has been found than the general increase of density toward the centre mentioned earlier. McCuskey's extensive study of the distribution of stars of different spectral types *does* show a lot of structure for the early-type stars, but it seems of a rather irregular nature and is not well understood. As an illustration of this notice the density distribution for B5 stars and B8-A0 stars in figures 15 and 16.

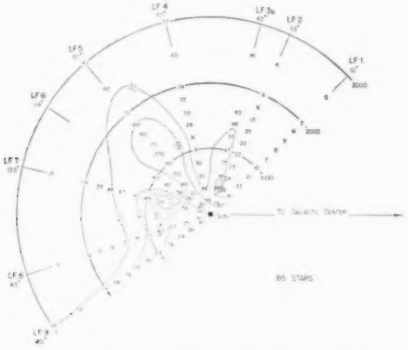


FIG. 15—The large-scale distribution in the galactic plane of the B5 stars. The density is expressed as the number of stars per 10^7 cubic parsecs.

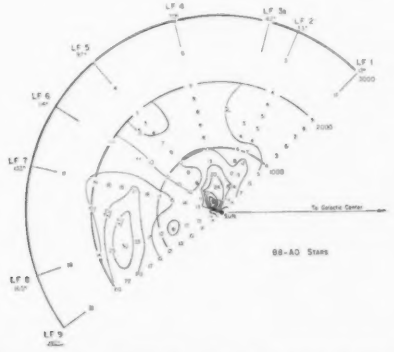


FIG. 16—The large-scale distribution of the B8-A0 stars in the galactic plane. Contours of equal density indicate approximately regions of high and low density. The units of density are stars per 10^6 cubic parsecs.

The introduction of Morgan's new spectral and luminosity classification system, and of Johnson's photometric *UBV* system, gives more accurate distances of open clusters and associations. Shown in figure 17 is

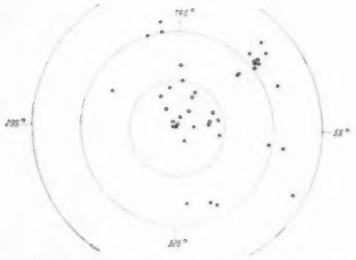


FIG. 17—Distribution of 40 open clusters in the galactic plane. The sun is at the mid-point of the circle; distance between circles is 1 kpc.

the distribution of open clusters from a compilation by Becker and Stock. Figure 18 shows the distribution of stellar associations as deter-

FIG. 18—Distribution of stellar associations as determined by Morgan, Whitford and Code.

mined by Morgan, Whitford and Code, and again concentrations are clearly seen. The open circles are single stars. It was believed at the time that the spiral arms had an inclination of about 55° to the radius. The hydrogen arms, however, show an inclination of 85°. Spiral arms in extragalactic systems usually have inclinations of around 80°. Part of the deviating value found from the optical work must be due to the

inclusion of the single stars, which probably should be left out of consideration as having distances which are too uncertain. Another part may be due to the fact that the optical evidence of spiral arms covers only a few kiloparsecs, and a real irregularity in the structure may be incorrectly considered as a regular feature. Such a feature is, I think, the upper branch of associations near the sun, which is largely responsible for the low inclination. From the hydrogen structure one gets the impression that it is really an inter-arm connection, of which several examples are known. Figure 19 shows a comparison between the hydrogen

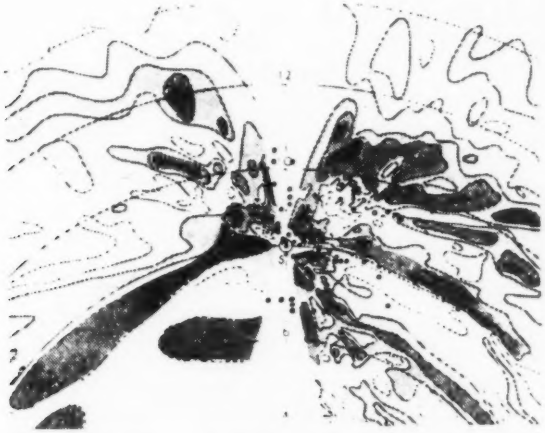


FIG. 19—Comparison between hydrogen structure and distribution of emission regions, open clusters and associations, given as dots.

structure and the distribution of emission regions, open clusters and associations, all given as dots. The most serious discrepancies are in the direction of Perseus-Cassiopeia, and toward Cygnus. The latter may be due to an incorrect separation of contributions, which in this direction are particularly difficult to disentangle. The discrepancy toward Perseus-Cassiopeia is of a more serious nature. It may well have something to do with a known velocity anomaly in this region, which would affect the distance obtained for this hydrogen arm. A direct comparison of radial velocities of stars, and of the interstellar gas from optical interstellar absorption lines shows that in many cases the gas has a *larger* velocity than the stars, while the gas is of course nearer than the stars. This would suggest that the gas clouds in this direction are moving in non-circular orbits, which means that the distance to the hydrogen arm in

this direction is incorrect, but it may well be that the real solution is less simple.

At all times we should keep in mind that hydrogen structure and optical spiral structure may not *have* to be identical. In fact, it is well to point out that as yet we do not understand how spiral structure can be maintained. The change of angular velocity with distance is so rapid that the hydrogen structure we see now will be wound up still further and washed out into a continuum within a billion years. If we calculate what the hydrogen structure looked like in the past, we find that in the solar neighbourhood 430 million years ago we did not have any spiral structure but just a radial bar. It is inconceivable that spiral structure would be so short-lived a phenomenon, because we see it in many external galaxies. Possibly mass transport from arm to arm, or along an arm—forward on the inner side of a spiral arm and backward on the outer side—could maintain spiral structure, but the theory has not been worked out as yet, and it remains to be seen how good our assumption of circular velocities on the average really is.

Now I should like to mention some work of interest at wave-lengths other than 21 cm. Figure 20 shows a survey at 200 Mc./s. and I am

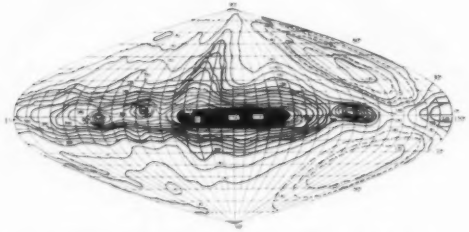


FIG. 20—Intensities of radio emission at 1.5 metres.

showing this to indicate two anomalies, namely, the minimum in the galactic plane at longitude 190°, 45° from the anticentre direction, and the bright extension to high galactic latitudes at longitude 0°. One is reminded here of a puzzling feature at optical wave-lengths. Hiltner, from measurements of interstellar polarization, found that the directions of linear polarization show strongest alignment at longitude 102°. On the usual assumption that the magnetic lines of force run parallel to the spiral arms, this leads to an inclination of the arm of 45°, thus apparently confirming the inclination from optical data discussed before. Possibly this is related—through the magnetic field which is a common

denominator in all these phenomena—to the two features of the distribution of non-thermal radiation, both of which are about 90° away from longitude 102°.

At high frequency, an interesting study was made by Westerhout at 1390 Mc./s. By comparing the distribution of brightness in his survey with one by Mills at 85 Mc./s., he could separate the thermal and non-thermal components, which at 1390 Mc./s. contribute about equally much. The thermal component is due to free-free transitions in ionized gas, mostly hydrogen. By assuming axial symmetry Westerhout could determine the distribution of ionized hydrogen in the Galaxy; no attempt was made to find spiral structure. The density of ionized hydrogen turned out to be about 5 per cent. or less that of neutral hydrogen.

At the much lower frequency of 85 Mc./s. Mills used his survey to get some interesting evidence of structure. He noticed that the brightness near the galactic plane decreases in more or less discrete steps when going away from the galactic centre. On the assumption of axial symmetry this leads to strong peaks in the volume emissivity at various distances from the centre of the Galaxy. According to Mills these positions correspond to spiral arms in the 21-cm. survey from the southern hemisphere and he managed to fit an equi-angular spiral to the data as shown in figure 21. However, the Sagittarius arm, seen tangentially at longitude 18°, is not represented in this model.

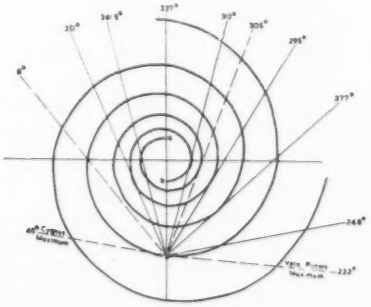


FIG. 21—The spiral pattern of the Galaxy as defined by 'steps' in the longitude distribution of the disk component. The directions of the steps are indicated by the lines radiating from the solar position. When the line is dotted the step is not very pronounced. The directions of the two pronounced maxima in Cygnus and Vela are shown by dotted lines.

Now I should like to return to the 21-cm. results. One of the striking results was, that the total mass of hydrogen is only around 1 per cent. of the total mass of the Galaxy, a result of great importance

for the discussion of the evolution of the Galaxy. Thus it is of interest to investigate more closely the hydrogen densities derived. Two assumptions were made in the derivation of densities: (1) uniform spin temperature, taken to be 125° K., (2) no small-scale density fluctuations. As shown by Purcell and Field the spin temperature, which characterizes the relative populations of the two energy levels involved, may be identified with the kinetic temperature of the gas. It can easily be seen that if the temperature assumed is too low, the hydrogen densities have to be revised downward. If the temperature has to be decreased, we must drop the assumption of uniform temperature, because a brightness temperature of 125° K. *is* observed at some point in Cygnus, and the densities have to be increased by an unknown factor, which might be quite large. I think that absorption spectra at 21-cm. wave-length will furnish the information we so badly need here. Figure 22 shows the

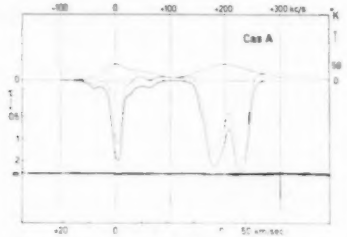


FIG. 22—21-cm. absorption profile in direction of the radio source Cas A.

absorption spectrum in the direction of the source Cassiopeia A. The primary information obtained from absorption spectra is the optical depth, and it may easily be seen that varying the assumed kinetic temperature has an effect on the hydrogen density which is opposite to the one discussed for the case of emission. One might argue now that statistically the density of gas obtained from the emission work and the absorption work should be the same. This can be done statistically only, the effective antenna beam area in case of absorption in general being much smaller than in the case of emission. We cannot do this as yet since only two radio sources, Cygnus A and Cassiopeia A, can be used for the purpose and two, even for astronomers, is not really a statistical sample! The ratio of absorption density to emission density for the two cases is 1 to 3, and 2 to 1, respectively.

The second assumption of importance was the neglect of small-scale fluctuations. This assumption will lead to an underestimate of the

hydrogen densities, because it is the case leading to the smallest degree of self-absorption. The absorption spectrum of Cassiopeia A shows some very dense hydrogen clouds, with optical depth between 2 and 4, and masses of 100 to 1,000 solar masses. The effects of this cloudiness may be studied in conjunction with the statistical determination of spin temperature just described. We would expect, again statistically, that the densities derived from absorption work cannot be lower than those from the emission work and thus we should be able eventually to establish a lower limit to the spin temperature.

Finally, I would like to say a few words about the dynamics and the evolution of the Galactic System.

In the field of dynamics the determination of the rotational velocities in the interior parts of the System has been of considerable importance. It has enabled us to get some idea of the distribution of mass throughout the Galaxy, which in turn provided the rotational velocities in the outer parts that were required for the determination of hydrogen structure.

Speculations on the evolution of the Galaxy were really started when it was realized that only 1 or 2 per cent. of the mass of the Galaxy was in the form of interstellar gas (near the sun this percentage is 10 or 20). This suggested that the Galaxy is, genetically speaking, old, since almost all gas has been used up in the process of star formation. The low gas content forms an important datum in present theories on the evolution of the solar neighbourhood and of the Galaxy as a whole, and it has been shown that the almost uniform density of gas over the galactic plane (except for spiral structure) may be a logical consequence of the effects of star formation.

I hope I have been able to indicate the close relationship between optical and radio astronomy in the field of galactic structure. Most information in optical astronomy deals with stars, in radio astronomy exclusively with the interstellar gas. We know that stars are formed out of the gas, and that evolving stars return part of their mass back to the interstellar medium. Symbolically one might say, this expresses the dual role of optical and radio observations in the field of galactic structure.

I fully realize that there are many interesting aspects which would be covered by the title of this talk, and which I have not discussed, such as the possible concentration of gas in associations and open clusters, the possibility of determining relative positions and relative motions of emission regions and interstellar gas through 21-cm. absorption spectra of thermal sources, and the structure and dynamics of the very central region of the Galaxy. In many of these fields work has only just started

and there can be no doubt that many interesting developments may be expected in the future. May I conclude by wishing that the contributions of the one-day old Dominion Radio Astrophysical Observatory will aid substantially in solving the puzzles of galactic structure in the best traditions of Canadian astronomy.

SOLAR EMISSION AT TEN CENTIMETRE WAVE-LENGTH, 1947–1960

By Arthur E. Covington
Radio and Electrical Engineering Division, National Research Council, Ottawa, Ontario

Abstract

Three graphical representations involving the 10.7-centimetre solar radiation for a period somewhat greater than a sun-spot cycle will be presented. The first parameter is a pair of numbers giving the highest and the lowest values of daily flux for each month, the second parameter is the monthly mean of the daily flux, and the third is a monthly count of the number of bursts in various intensity intervals.

Daily observations of the total 10.7-centimetre solar radiation have been made since 1947 at the laboratories of the National Research Council in Ottawa, using a parabolic reflector 4 feet in diameter. The results now extend over a period of time somewhat greater than a sun-spot cycle and will be displayed in a number of graphs. The well known relationships with other indices of solar activity such as sun-spot area, etc., will not be emphasized, but rather some of the characteristics of the radiation itself. The details of the observations have been reported in a previous issue of the Journal (Covington 1951), as well as elsewhere (Covington 1948), while the numerical values related to the observations have appeared in "The Quarterly Bulletin of Solar Activity" since 1948; and, since 1957, in the monthly bulletin, "Solar-Geophysical Data, Part B" issued by the Central Radio Propagation Laboratories of the U.S. National Bureau of Standards. The observational material which is recorded each day is readily put into two categories: (1) the total emission from the solar disk, and (2) the sudden enhancements above the daily level.

The first category includes an emission from the undisturbed solar surface associated with a radio disk about 10 per cent. larger than the visible 32 minutes of arc solar disk, together with a slowly varying emission which is associated with centres of sun-spot activity. The accuracy with which the two components can be separated has a direct bearing upon the accuracy of the answer to the question of the variation of the quiet sun during the sun-spot cycle. High resolution scans of the sun give directly a large measure of separation of isolated active regions from the background and have shown that the radio emission from an active region follows the plage development more closely than the development of the area of sun-spots. In particular, it has been observed that the radio emission lingers longer than the visible sun-spot activity. At the

time of maximum sun-spot activity, the observed plage regions are extensive and persistent, and appear to indicate that the radio emitting area associated with this activity would likewise be intense and persistent, completely obscuring the basic emission originating from the undisturbed solar disk. However, at or near sun-spot minimum, when spots are not present for many months at a time, observations show (Covington, Medd, Harvey and Broten 1955) that there is every indication that a true disk emission will be recorded by itself. Two different analyses of the data have appeared (Covington and Harvey 1960; Allen 1957) which show that the quiet sun emission varies from a level of 100 flux units in 1948 to 70 units in 1954, and give a measure of the quiet sun variation over this period if the previously noted difficulties are accepted as introducing some unknown limit to the accuracy of the variation.

The first parameter was chosen to show the amplitude of the persistent 27-day variation of the slowly varying component of solar flux. It is a pair of numbers giving the highest and the lowest values of daily flux for each month, and in figure 1, is represented by a bar. This variation

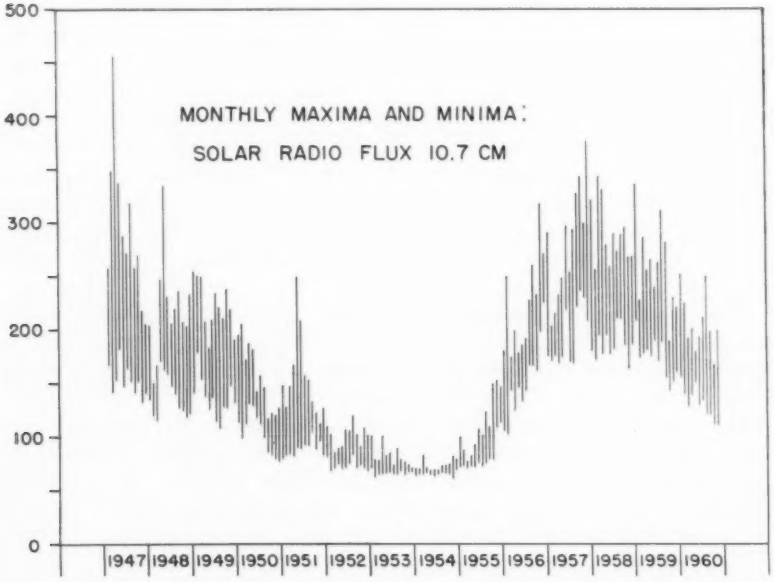


FIG. 1—Plot of monthly high and low of 10.7-centimetre solar flux. (Units are 10^{-22} watts/metre^2/c./s.)

arises from the rotation of the sun which carries a preponderance of spots on one side of the sun into maximum visibility and then into obscurity on the back side of the sun. These regions generally have a lifetime of several months and occur in different longitudes of the solar disk. The lower envelope of the band of bars thus traces out the lowest total value of flux from the quieter side of the sun and might be considered as a first approximation to the emission from the quiet solar disk, while the upper envelope traces out the maximum intensity given by the most disturbed side of the solar surface. The average emission from the sun is between these two extremes and is given approximately by the monthly mean of daily flux values. This is the second parameter which has been considered and is given in the upper curve of figure 2. In

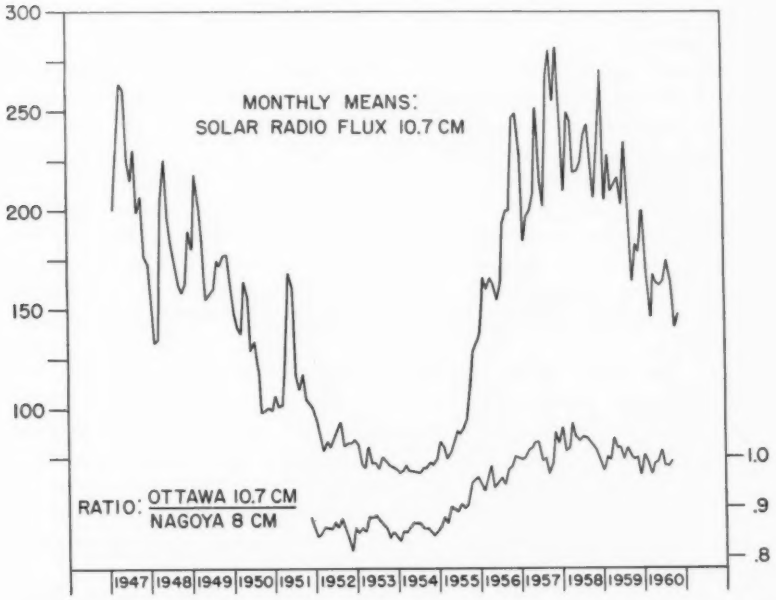


FIG. 2—*Upper curve*: Monthly means of 10.7-centimetre solar flux. (Units are 10^{-22} watts/metre^2/c./s.) *Lower curve*: Plot of ratio of monthly mean flux values: Ottawa/Nagoya.

both figure 1 and the upper curve of figure 2, the low values of flux coincide with sun-spot minimum, while the peaks—in 1947 and 1958—coincide with peaks of sun-spot activity.

A long series of solar observations similar to those recorded at Ottawa has been made at the Research Institute of Atmospherics, Nagoya University, Japan, on a wave-length of 8 centimetres instead of 10.7 centimetres. Theoretical considerations indicate that the emissions at these two wave-lengths originate from two adjacent levels in the chromosphere of the solar atmosphere, and it is expected that the intensity of the two emissions should be similar. This is indeed the case, but in the presence of the slowly varying component of sun-spot emission, this similarity, or any small departure from a correspondence, are both hard to recognize and must be enhanced by forming the ratio of monthly mean flux levels. Such a ratio—Ottawa to Nagoya readings—has been plotted in the lower curve of figure 2, and shows a gradual variation from a value of 0.85 at a time of sun-spot minimum to a value of 1.00 at a time of high activity. The constant errors associated with the absolute measurements of flux are estimated to be ± 7 per cent., and are of sufficient magnitude to explain most of the deviation from a ratio of unity. On the other hand, the variation of accidental errors may be judged from the variation of the ratio in the first three years of simultaneous observation which includes sun-spot minimum. At this time, only the quiet sun emission is present and serves as an intensity reference, while at sun-spot maximum, the slowly varying component with its different spectrum is present as a second component. On this basis, the gradual increase in the ratio of the readings commences at the beginning of the present sun-spot cycle, appears to be significant, and could be interpreted as a true small difference in the spectra of the radio emissions.

It will be interesting to see how this ratio varies in the future, particularly the value which will be obtained during the next sun-spot minimum. The ratio is sensitive to the operating characteristics of the two stations which are intercompared, as well as to the observed solar phenomena. Its interpretation has much significance—for example, if the ratio in 1965 should return to the value obtained in 1954, it may reasonably be concluded that the spectrum of the slowly varying component, in relation to the spectrum of the quiet sun, has changed as indicated by the ratio.

The second category of solar noise observations consists entirely of the sudden enhancements of solar emission usually associated with solar flares. This close association with the flare suggests that the frequency of occurrence of the radio event will provide another indication of the variation of the sun-spot cycle and the third parameter—the number of bursts observed in a month—has been chosen with this in mind. However, a classification of bursts according to intensity has been introduced

in order to separate the great bursts of noise which are always associated with the largest of flares, from the small bursts of noise which are only sometimes associated with flares. The intensity classification of bursts has been based upon a unit of flux which is one-tenth that of the quiet sun emission which was observed at sun-spot minimum in 1954 (here taken as 75 units instead of the actual 69 flux units). The four classes of intensity level are from 0 to 7.5 units, from 7.5 to 75 units, from 75 to 750 units, and over 750 units. The small bursts are invariably only a few times more intense than the residual noise fluctuations of the receiver, and the number recorded may be largely dependent upon the operating condition of the radiometer. The last class is composed of the great bursts, which are invariably associated with flares of great geophysical interest. The plots of the number of bursts in the four categories, as shown in figure 3, show variations with the sun-spot cycle. The graphs are rough since they represent the counts of a number of infrequent events, but nevertheless give a good indication of the sun-spot cycle. Since the monthly hours of observation are somewhat lower before 1950

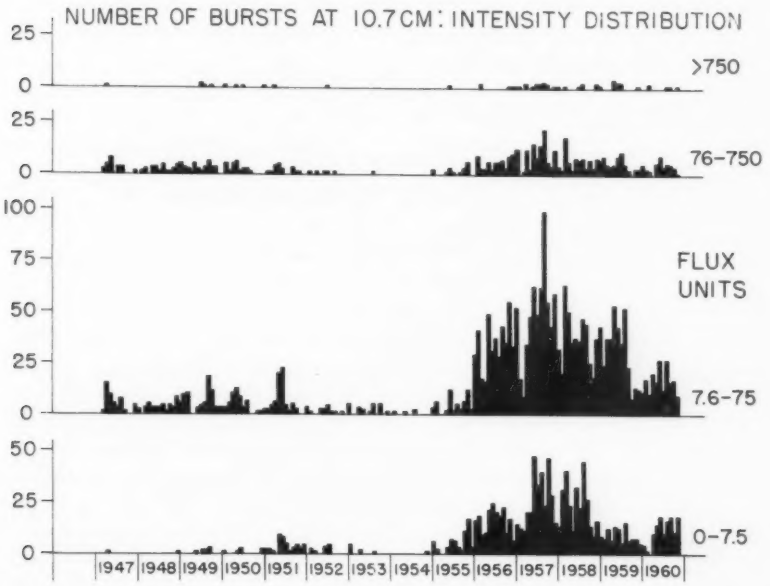


FIG. 3—Plots of number of bursts observed in four intensity classes. (Units are 10^{-22} watts/metre^2/c./s.)

than after, a valid intercomparison of the strength of the two cycles is not possible with these graphs.

Acknowledgment. The author gratefully acknowledges the assistance of the staff of the Radio and Electrical Engineering Division of the National Research Council during the many years this programme has been in operation.

References

Allen, C. W. 1957, *Monthly Notices Roy. Astro. Soc.*, vol. 117, p. 174.
Covington, A. E. 1948, *Proc. I.R.E.*, vol. 36, p. 454.
Covington, A. E. 1951, *J. Roy. Astron. Soc. Can.*, vol. 45, p. 15.
Covington, A. E., Medd, W. J., Harvey, Gladys A., and Broten, N. W. 1955, *J. Roy. Astron. Soc. Can.*, vol. 49, p. 235.
Covington, A. E. and Harvey, Gladys A. 1960, *Astrophys. J.*, vol. 132, p. 435.

THE SUPERNOVA IN NGC 4564

By Sidney van den Bergh and R. C. Henry
David Dunlap Observatory, University of Toronto, Richmond Hill, Ontario

Supernova explosions are among the most violent events known to astronomy. Recently interest in supernovae has been stimulated by our increased understanding of stellar evolution and by the observation that supernova remnants are powerful sources of radio radiation. Observations of the spectra and light curves of supernovae suggest that at least two distinct types of supernovae exist. The most luminous supernovae are those of Type I which reach a mean photographic absolute magnitude of -18.4 at maximum light and during their later stages exhibit an exponential decline in luminosity. Supernovae of Type II are considerably fainter, attaining a mean photographic magnitude of -15.9 at maximum light, if a Hubble constant $H = 120$ km./sec./Mpc. is adopted. Supernovae of Type I have been observed to occur in E, Sb, Sc and Ir galaxies. Supernovae of Type II occur most frequently in Sc galaxies but have also been observed in galaxies of Type Sb. Type II supernovae are observed predominantly in the outer, spiral arm regions of spiral galaxies. This suggests that they are associated with a young stellar population. Possibly they are due to the explosion of very young, supermassive stars. This suggestion receives support from observations by Evans and Thackeray (1950) of the ring-shaped emission region N70 (Henize 1956) in the Large Magellanic Cloud. This nebula exhibits the same peculiar filamentary structure (van den Bergh 1960) that has been observed in a number of old galactic supernova remnants such as the Cygnus Loop. A star cluster, presumably containing young stars, is located at the exact centre of the ring-shaped nebula N70. It is, therefore, tempting to assume that the supernova which gave rise to the N70 nebulosity was a member of this cluster.

Our understanding of supernovae is greatly handicapped by the fact that supernovae occur so rarely and, because of their great distance, are usually extremely faint. The discovery of a relatively bright supernova by Romano of the Padua Observatory on May 9, 1961 (Liller 1961) in the elliptical galaxy NGC 4564 is, therefore, of considerable interest. On the night of May 19/20, 1961, the visual magnitude of the supernova was estimated to be approximately 11. According to Holmberg (1958) NGC 4564 has an integrated visual magnitude of 11.33 so that the supernova was probably slightly brighter than the galaxy in which it occurred. NGC 4564 is probably a member of the Virgo cluster, which

has a distance modulus of about 30, so that the absolute visual magnitude of the supernova was approximately −19. This high luminosity and the fact that NGC 4564 is an elliptical galaxy suggest that the supernova was of Type I. Bertola at the Asiago Observatory has obtained a spectrum of the object and reported it as probably of Type I.

Figure 1 shows a microphotometer tracing of a very weak spectrum

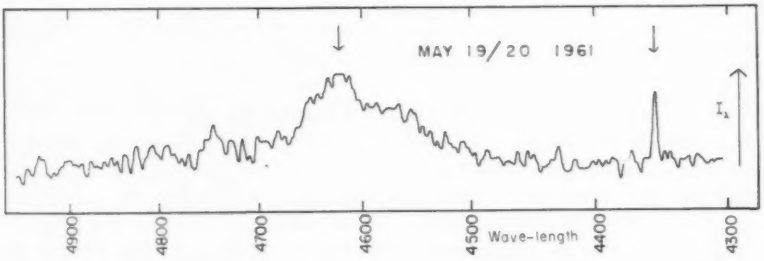


FIG. 1—Microphotometer tracing of the supernova in NGC 4564. The trace shows a broad emission feature centred at λ 4620 and a terrestrial mercury line at λ 4358. The ordinate, I_λ, is the intensity at that wave-length.

of the supernova in NGC 4564 which was obtained during a three hour exposure on 103aO emulsion during the night of May 19/20, 1961. The original spectrogram has a dispersion of 66 A./mm. at Hγ and was taken with the 12.5-inch spectrograph attached to the 74-inch telescope of the David Dunlap Observatory. A slit width corresponding to 3.3 A. at the plate was employed. In addition to a strong mercury line at λ 4358, which arises from commercial lighting, the tracing shows only a broad emission feature centred at λ 4620.

Observations by Minkowski (1939) of the Type I supernova in IC 4182 show that the emission band near λ 4600 does not become the dominant feature in the blue part of the supernova spectrum until more than ten days after maximum light. Assuming the development of the supernova in NGC 4564 to parallel that of the supernova in IC 4182 one may probably conclude that maximum light occurred at least ten days prior to May 19/20. In his 1939 paper, Minkowski notes that the most prominent features in supernovae spectra gradually shift to longer wave-lengths. Figure 2 shows the wave-lengths of the maximum of the λ 4600 feature in IC 4182, corrected for redshift on the assumption that this dwarf irregular galaxy is a member of the Canis Venatici Cluster, as a function of time after maximum light.

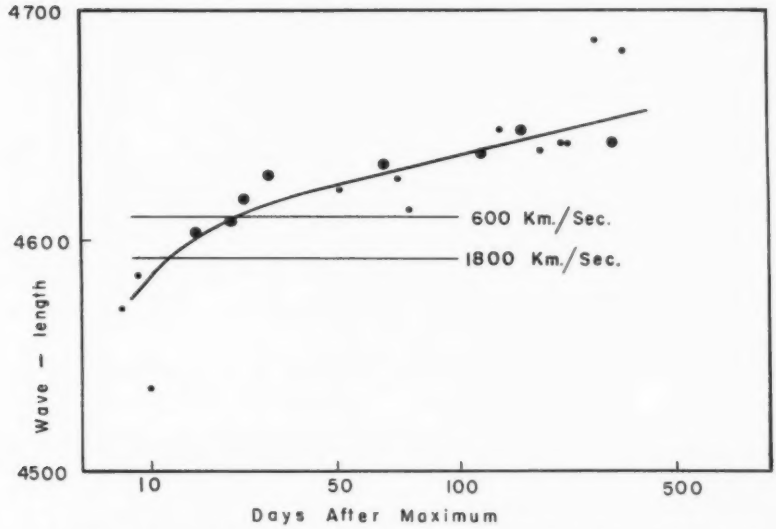


FIG. 2—Positions of the λ 4600 feature as a function of time after maximum light from Minkowski's observations of the supernova in IC 4182. Accurate observations are denoted by large dots. Horizontal lines indicate the position of the λ 4600 feature in NGC 4564 for assumed redshifts of 600 and 1800 km./sec. The figure indicates that the supernova in NGC 4564 was probably between 10 and 20 days past maximum on May 19/20.

The position of the λ 4600 feature in NGC 4564, corrected for redshift, on the assumption that this galaxy has a radial velocity between 600 and 1800 km./sec., is shown in figure 2 by two horizontal lines. (Most of the redshifts of members of the Virgo Cluster lie within this range.) The data in the figure suggest that maximum light occurred between 10 and 20 days prior to May 19/20. It should, of course, be emphasized that this conclusion is quite uncertain and depends critically on the assumption that the supernovae in NGC 4564 and IC 4182 were comparable in all respects.

REFERENCES

Bergh, S. van den 1960, *Zs. f. Astrophysik*, vol. 51, p. 15.
Evans, D. S. and Thackeray, A. D. 1950, *R.A.S., M.N.*, vol. 110, p. 429.
Henize, K. G. 1956, *Ap. J. Suppl.*, vol. 2, p. 315.
Holmberg, E. 1958, *Lund Medd.*, ser. II, no. 136.
Liller, M. H. 1961, *Harv. Announcement Card*, no. 1528.
Minkowski, R. 1939, *Ap. J.*, vol. 89, p. 156.

TAMPERING WITH THE TIDES

By F. Keith Dalton
Toronto Centre

The very familiar expression, "The Balance of Nature", refers to the stability of the processes of production, development and maintenance of all forms of life and control in certain proportions, the operation of the unalterable physical and chemical laws, and the smooth and steady running of the world of nature on this basis, even allowing some gradual change.

In some cases, man decides to tamper with this orderly progression, for his own benefit or only for his convenience, and then often finds that the features which he previously accepted as normal are really interdependent and that in creating his "improvement" he has withdrawn some control. Unexpected troubles now become prominent and may even have disastrous effects. As an example, in many instances where pest destruction has been applied, it has resulted in the now-uncontrolled rise of trouble from some other pest or the loss of some natural help from some particular bird or insect. On the other hand, the drying up of swamps to prevent the breeding of mosquitoes, the construction of retaining walls against flooding of land and providing irrigation appear wholly desirable.

The ocean tides are natural phenomena of a very complicated type. However, if one considers that their normal behaviour is to roll over the oceans and stop on the receiving shores, then any obstacle or treatment which changes this simple operation may be considered as interfering with their flow. Under this definition, there can be both natural and artificial interference.

Natural Interference

Such objects as islands, steep coasts, narrowing inlets and the rising beds of estuaries or bays exposed at low tides alter the performance of tidal flow. While islands and steep shores cause only a slight rise in water levels at high tides, the bays and estuaries, which usually are narrower at the head than at the mouth, cause a gradual rise in both mean water level and range as the tides proceed in from the sea. In some cases this rise may become quite appreciable as in the Bay of Fundy and Baie St. Michel in France where the mean water levels rise as much as twenty feet and the range of tide at the head of the bay may be twice as high as at its mouth.

This effect in the Bay of Fundy and Minas Basin—from Eastport, Maine, to Truro, Nova Scotia—is shown in figure 1. Here the mean

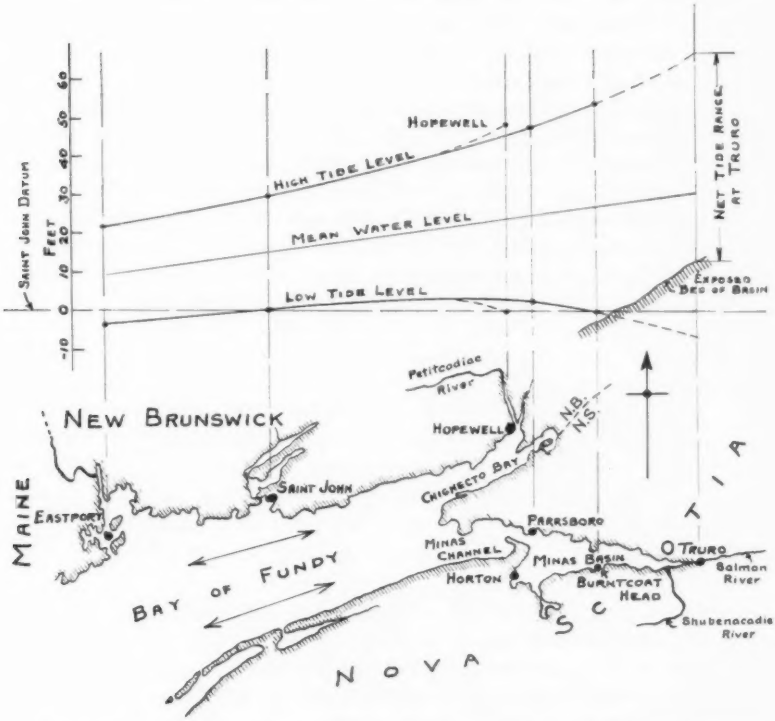


FIG. 1—Gradient of mean water level with increasing range of tide from Eastport, Maine, to Truro, Nova Scotia—based on Saint John datum and showing locations of measuring stations.

water level rises steadily with a gradient of one foot in every thirteen miles due to the progress of the tides.

The highest range of tide in the world, 53½ feet, occurs at Burntcoat Head on the south shore of the Minas Basin about 25 miles west of Truro which stands at the apex of this triangular bay. While, at first, this may appear contradictory to the principle of increasing tide ranges —for one could reasonably expect higher tides at Truro—it will be seen in the graph that between these points the bed of the Basin is exposed at low tide thus preventing the full development of the tidal cycles by

cutting off the lower loops. This causes certain inconvenience too for all wharves in the region are dry at low water.

The resultant *net* tide range at Truro is only slightly less than at Burntcoat Head but if the Basin were deep enough the fully developed tide cycle could reach a range of 65 to 70 feet—the direct vertical distance between maximum high and low waters.

Tidal Bores. Interference by mud flats or ledges well above low tide levels, either at the entrances to estuaries or farther upstream, and in regions where the tides rise very rapidly produces the interesting phenomenon known as a "Pororoca", or tidal bore, the incoming tides proceeding up the estuary with a definite and steep wave front whose steady progress at velocities of 8 to 15 miles per hour, for different rivers, is very impressive—specially so for the astronomically-minded observer.

Some well-known tidal bores occur on the following rivers:

River	*Height of Wave Front*
	feet
*Petitcodiac—New Brunswick (Fig. 1)	3–5
Salmon and Shubenacadie—Nova Scotia (Fig. 1)	2–6
Amazon—Brazil	5–12
Araguary, Guana, Guajara—Brazil	5–15
Colorado—California and Mexico	3–7
Turnagain Arm—Alaska	5–6
Severn and Trent—England	4–5
Seine—France	8–9
Tsientang—China	2–11
Pegu—India	2–3
Hoogly—India	4–5

The Amazon is such a long river and the tidal bores progress so far that they create fresh-water bores in the upper reaches many feet above sea level. A series of five successive bores may all be running upstream at the same time—following one another about 150 miles apart.

Very high bores are dangerous to life and may be destructive to property for they have both the element of surprise and the terrific power of the oncoming tide behind them. They may catch workmen unaware or damage boats or other objects resting at too low levels. The Colorado River has been particularly severe in this regard. About 1875, the *Nina Tilden*, a stern-wheel steamer, capsized and was lost at the mouth of this river being carried away from her moorings by an exceptionally heavy bore. In September 1921, another steamer was capsized and lost with 130 lives. Tidal bores of great violence have occurred on this river since the earliest observations but now, with a measure of flood

*See this JOURNAL, vol. 45, p. 225, 1951

and navigation control, the bores are distinctly smaller and less violent for the incoming tides meet little opposition from the river flow.

Various Effects of Interference. In addition to tidal bores on many widespread rivers, the Tide Tables of the world mention some varied phenomena evidently also caused by interference due to contour of land or shape or depth of water passages. A double high water occurs on the Seine River in France, below Rouen, the second following the first (predicted) high water by one or two hours according to spring or neap tides. At Portland, on the south coast of England, a double low water appears, the second being about 3 hours 25 minutes later than the first. Nearby, at Bridgwater, while the high tides vary in height low tides show practically no variation. On the Humber River in England, and also on the St. Lawrence between Quebec and Three Rivers, neap tides run lower than spring lows—a reversal of the usual relation.

In many places, the basic semi-diurnal tides become very definitely diurnal—only one high and one low tide per day. Tides at Tahiti Island ignore the moon when new or full, being timed by the sun alone, and virtually vanish at the quarter moons.

Where the tides flowing into an estuary meet a rapids which interferes with their progress, they attempt to overcome this obstacle and may succeed in doing so completely, in which case they reverse the flow of the river upstream. The most spectacular instance of this in Canada is at Saint John, New Brunswick, figure 1. (See this JOURNAL, vol. 54, p. 157, 1960.)

Seiches. Further interesting phenomena, listed in the Tide Tables, are the "seiches"—damped standing oscillations in inland lakes and seas and in coastal inlets and harbours, *following* an unbalance of surface levels of the body of water by winds or due to difference between barometric pressures on two or more separated areas of the same basin, figure 2. These resonant oscillations, being long-period standing waves, are created by the above forces, then maintained by the inertia of the water and by gravity but damped by the *interference* of internal molecular and *bottom surface* friction forces and, as a rule, are most noticeable in the direction of the longest dimension of the lake or inlet, figure 3. The whole volume of water in any given basin oscillates synchronously, not only the upper part near the surface, and the periods differ widely from that of the tides so seiches do not appear to be influenced by lunar or solar gravitational attraction.

The seiche decays exponentially, according to the familiar formula:

$$A = A_0 e^{-at},$$

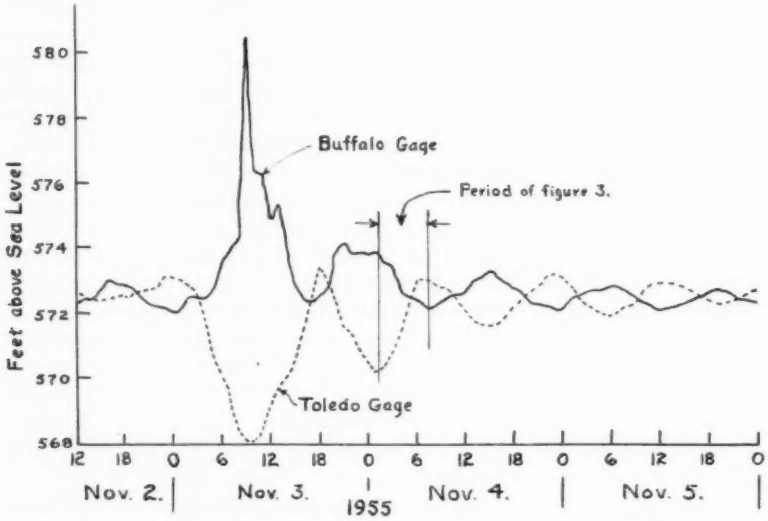


FIG. 2—Wind tide and seiche on Lake Erie. While water levels rose at the east end (Buffalo), those at the west end (Toledo), would fall—and vice versa—showing exponential decay during sixty hours. (Credit: L. Bajorunas, U.S. Army Corps of Engineers.)

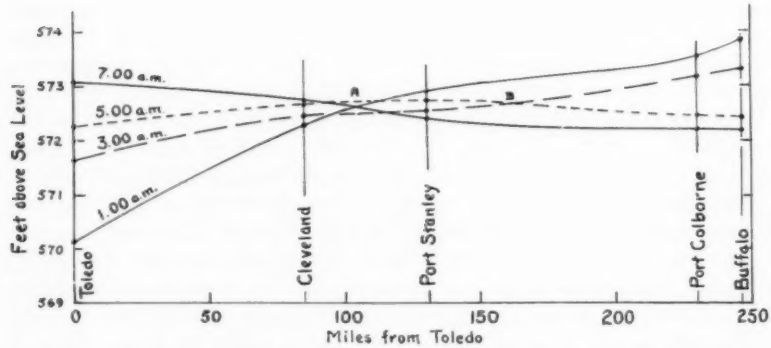


FIG. 3—Water level profiles of seiche on Lake Erie, during the period: 1:00 a.m. to 7:00 a.m. on November 4, 1955. See figure 2. The node of the seiche, *A*, east of Cleveland, evidently moved farther east, *B*, during part of this cycle. (Credit: L. Bajorunas, U.S. Army Corps of Engineers.)

where: A_0 = initial range of seiche, A = range of seiche after t hours, a = the damping factor which varies according to depth of water, irregularity of bottom and shores and amount of energy lost to outside areas—rivers and bays.

For the Great Lakes,* on the long axis of each, values of a were found to be: Lake Superior: 0.04; Lake Erie: 0.06; Lake Huron: 0.09; Lake Ontario: 0.11; Lake St. Clair: low seiche range, high damping factor; Lake Michigan: no longitudinal seiches recorded.

The period, T, of the seiche, for the first few cycles, is computed, approximately, by the formula: $T = 2L/\sqrt{gD}$, where L = length over the seiche area; D = depth of seiche area; g = acceleration of gravity.

Seiches were first discovered in 1730 and first studied systematically on Lake Geneva. They were considered mysterious but thought to result from tidal disturbances. Sir Alexander Mackenzie, Canadian explorer, gave the following description of a seiche that occurred on Lake Superior about the year 1780:

> A very curious phenomenon was observed some years ago at the Grande Portage for which no obvious cause could be assigned. The water withdrew with great precipitation, leaving the ground dry that had never before been visible, the fall being equal to four perpendicular feet, and rushing back with great velocity above the common mark. It continued falling and rising for several hours, gradually decreasing until it stopped at its usual height. There is frequently an irregular influx and deflux which does not exceed ten inches, and is attributed to the wind.

In May 1952, strong seiches appeared on Lake Huron with variations of about three feet at Goderich and Collingwood.

In addition to being observed on four of the Great Lakes and many well-known coastal inlets in the western hemisphere, the Tide Tables list seiches at sixteen points on the shores of Japan and Formosa, some of these bays having sand bars and some being protected from the sea by series of islands across the mouth. In the latter cases, the seiches have periods from 10 to 90 minutes with ranges from 0.7 to 3 feet, and surmount the tides to give resultant water levels.

Due to lunar and solar attraction, tides must occur on inland seas, lakes, ponds and pools—even in a teacup—but usually these are not readily discernible on account of higher amplitude of waves. However, these tides co-exist with the seiches and may appear in analysis of measurements.

Seiches can be so strong in harbours that they severely damage moored ships due to the horizontal movement of the water at the nodes of such resonant oscillations. In Table Bay Harbour, Capetown, in 1940, a large

*L. Bajorunas, U.S. Army Corps of Engineers (Detroit).

vessel of 42,000 tons broke all moorings and moved back and forth through about 20 feet on a seiche with a 1.8-minute period.

A few seiche measurements are as follows:

Location	*Period*	*Range*
Lake Geneva	73 min. (longitudinal)	6 ft.
	10 min. (transverse)	—
Lake Huron*	7 hr. (longitudinal)	—
	3½ hr. (transverse)	—
Georgian Bay*	5 hr. (longitudinal)	—
	2 hr. (transverse)	—
Manitowaning Bay*	80 min. (longitudinal)	—
	30 min. (transverse)	—
Lake Erie (Figs. 2 and 3)	15 hr. (longitudinal)	12½ ft.
Lake Ontario	7 hr. (longitudinal)	2½ ft.
Takao, Formosa	13–25 min. (longitudinal)	—
Hiroshima, Japan	10 min. (longitudinal)	0.7–2 ft.
Nagasaki, Japan	35 min. (longitudinal)	2 ft.

Man-made Interference

One may prefer to consider that as all of the above phenomena have already continued for many millenia they are just taking their part in "the balance of Nature". However, on many occasions and in many places man has tampered with the tides by building dams, earthworks and causeways with unexpected consequences requiring protective or precautionary measures and even has produced conditions that can not be remedied.

Dams and Earthworks. The construction of dams across estuaries or at the mouths of coastal inlets, as is now being done in developing tidal power on a large scale, alters the levels of the water both above and below the dam. High tides upstream will be slightly lower than before because the incoming waters can not pass as freely through sluices or flood gates as they did prior to construction. These changes in tide levels may require rebuilding of wharves, relocating boathouses and various other alterations. If pumping be a feature of the operating cycle of the power development, conditions above the dam can be improved.

Where a two-pool power installation is constructed, as proposed for Passamaquoddy Bay (see this JOURNAL, vol. 55, p. 23, 1961), the range of tides in each basin is reduced to half of the previous range. With such change where fishing is an industry, the weirs and other works would have to be relocated and many of them modified but less damage by tidal currents is anticipated. The freezing of the ponds after the dams are built would necessitate dismantling the weirs for winter and rebuilding them in the spring.

It is expected that a power development here would disturb the

*See R. K. Young, this JOURNAL, vol. 23, p. 445, 1929.

lobster industry requiring relocation with the problem of finding cold saline water in the area without fresh water entering. Some varieties of fish may have difficulty in finding and passing the filling gates during the short period through which they are open. An adverse effect on the packing and shipping of sardines is feared from freezing of pools. Where tidal currents are eliminated, or even reduced, by building dams or causeways, proper disposal of waste may be prevented and thus cause pollution that could be disastrous to the fishing and other industries. Somewhat similar conditions would apply at various sites.

With a two-pool power installation, there is continual danger of widespread destruction due to a breach in the earthworks which protect the low pool from the sea. Land areas previously flooded by the tides but now having buildings would be inundated again. Wharves and other facilities that had been lowered for the new levels would be under water and unusable. Shipping and navigation could not function.

Canso Causeway. During the years 1952 to 1955, the Federal Department of Transport, assisted financially by the Province of Nova Scotia, built a 4,300-ft. rockfill causeway from the mainland to Cape Breton Island, figure 4, thus stopping the flow and ebb of tidal currents through the Strait of Canso and creating two new tidal inlets—one 13 miles long having its mouth at the Atlantic Ocean while the other, 5 miles long, became the head of St. George's Bay, at the east end of Northumberland Strait. The maximum depth of water here is 185 feet.

As explained earlier, when tides enter a bay or inlet the mean water level rises and the range of the tide increases also—from the mouth to the head of the bay, see figure 1. The Canso Causeway has changed tidal conditions in that area, where previously there was a flow back and forth, and now the tides on opposite sides of it differ distinctly in both type and range, figure 5. Also, they are out of phase so at certain times the tide is rising on one side of the Causeway but falling on the other side.

The tidal currents through the Strait of Canso were the result of semi-diurnal and diurnal components in the tides at both ends of this Strait. Over the area where the Causeway now stands the resultant tide levels at any given time were practically the same at all points of interest.

Upon completion of the Causeway, however, these components became quite different everywhere. On the north-west side, measured at Auld Cove, the semi-diurnal range decreased by nearly 25 per cent. while the diurnal range increased by about 50 per cent., giving a slight reduction in total tide range but with tides now prominently diurnal here, typical

FIG. 4—The Canso Causeway—for rail, highway and pedestrian traffic—looking south-west from Cape Breton Island with navigation canal and swing bridge in foreground. Nova Scotia mainland in distance. (Credit: Nova Scotia Information Service.)

of those in Northumberland Strait, and showing appreciable inequality in range of successive cycles. On the south-east side, measured at Port Hastings, conditions were reversed—the semi-diurnal range increased

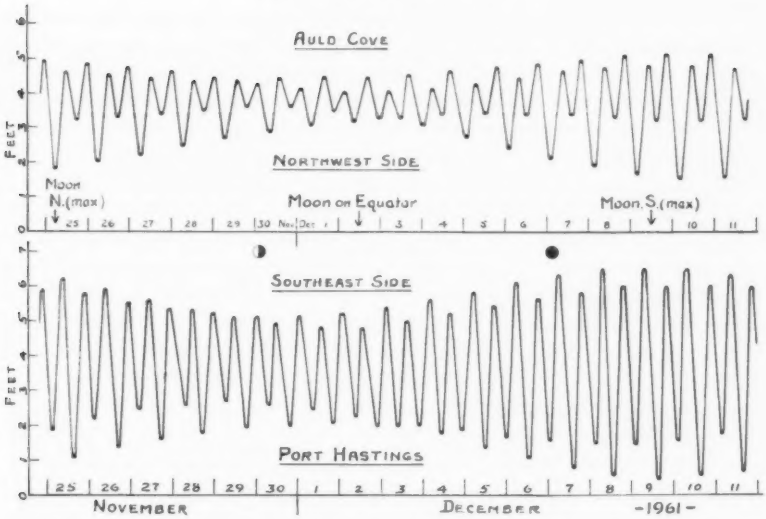


FIG. 5—Simultaneous tides on opposite sides of the Canso Causeway differ in type, range and phase—diurnal tides in west inlet; semi-diurnal tides in east inlet.

over 40 per cent. while the diurnal range decreased by about the same percentage—giving a net increase of about 1.2 feet in maximum range with strongly semi-diurnal tides, typical of those along the Atlantic seaboard which show usual synodic equality.

The Canadian Hydrographic Service, Ottawa, in their report of May 1957, after completion of the Causeway followed by close study of the new conditions, tabulated these changes in components for *mean range* of tide, as follows:

	Auld Cove		Port Hastings	
Date August	Semi-diurnal Range	Diurnal Range	Semi-diurnal Range	Diurnal Range
1952	2.52 ft.	0.96 ft.	2.82 ft.	0.82 ft.
1955	1.95 ft.	1.42 ft.	4.04 ft.	0.46 ft.

The mean water levels have been increasing gradually on both sides of the Causeway, both before and since its closure of the Strait. At Auld Cove this increase has more than offset the small reduction in range so there is a slight rise in tide levels here. At Port Hastings, a minor rise

in mean water level with an increased tide range give higher tide levels on this side.

Storms must be taken into account in considering maximum possible water levels. Prior to Causeway construction, effects of storms were about equal at Auld Cove and Port Hastings but now on several occasions conditions have been quite different.

The most marked instance of storm, in December 1954, lasted ten hours and raised the level $3\frac{1}{2}$ feet on the north-west side while depressing the level $1\frac{1}{4}$ feet on the other side—these effects coinciding. It appears from this and other evidence that the Causeway has changed the effects of storms to a greater extent on the north-west than on the south-east side. Storms may cause fairly rapid oscillations of sea level, like the storm surges of the North Sea, and when the peak of such a wave coincides with the crest of a large tide, exceptionally high water levels may be reached. Storm surges may account for as much as $2\frac{1}{2}$ to 3 feet in the high tide level here.

These tidal and storm relations necessitated a navigation lock in the Causeway to lift or lower vessels in either direction—a maximum of three feet due to tidal variations alone or possibly six feet when storms rage. For such small lifts, sector lock gates were used and this installation is recorded as the first application of this type of gate in Canada.

This Causeway now has been very successful as a structure for highway, rail, and pedestrian traffic for about six years but being openly exposed to weather conditions in St. George's Bay sometimes becomes almost impassable—more seriously so in winter.

Possibly the most unexpected and undesirable feature of the Canso Causeway was the prevention of migration of salmon through the Strait. Fishing grounds in the Margaree and other rivers on the west side of Cape Breton Island which have been famous meccas for anglers appeared now to have lost their attraction. The writer, in 1955, met several old-time visitors to the Margaree Forks area who expressed painful disappointment in that, after coming to this spot annually for thirty years or more, they now find it devoid of their favourite fish. However, this situation may readjust itself. Fishing grounds on the coast of New Brunswick do not seem to be affected so seriously.

Proposed P.E.I. Causeway. The people, industry, agriculture and the tourist agency of Prince Edward Island have long wanted a rigid highway and rail link between their Island and the New Brunswick mainland, a distance of about nine miles across Northumberland Strait where the maximum depth is recorded as 84 feet.

Four proposals have been well considered: (*a*) a bridge with sections

high enough for vessels to pass underneath, (*b*) a tunnel, (*c*) a partial causeway with a mile of bridge spans and (*d*) a full causeway with navigation locks. The first two proposals would not interfere with the flow and ebb of tidal currents in the Strait but are too expensive. The third, with enough bridge spans, would not seriously disturb the flow but the ramp approaches to the highest spans may be too steep for the railroad. The full causeway therefore appears to be the most feasible solution but obtaining suitable and sufficient rock fill at economic distance may become a problem.

The new causeway, as planned, would run on a straight line between Port Borden, P.E.I. and Bayfield, N.B., figure 6, and would stop tidal

FIG. 6—Site of proposed Prince Edward Island causeway bisecting Northumberland Strait and forming east and west inlets. With full causeway, tides will be higher here and in all nearby harbours.

currents completely. The east and west inlets thus produced would be, respectively, 70 and 60 miles in length. Normal tidal conditions of coastal bays would then apply but are predicted to be more harmful than with the Canso Causeway.

As the tides at both ends of Prince Edward Island are of the same type, the chief differences would be in levels on opposite sides of the proposed causeway, estimated at a maximum of ten feet. Locks with sector gates would likely be preferred here also.

If the gradients of mean water level in these inlets were as large as in the Bay of Fundy, namely, one foot in 13 miles, the tides would rise five feet on this factor alone. However, the ocean tides do not have as

free access to either end of the Island as at the entrance to Fundy so lower gradients are expected. High-water levels will rise $3\frac{1}{2}$ feet higher than at present and low levels drop $1\frac{1}{2}$ to 2 feet lower, giving a total increase of $5\frac{1}{2}$ feet in tide range—and severe storms will add to high tide water.

Extensive surveys of the shore lines of both inlets-to-be show that large areas of land would be flooded, much damage would be caused by erosion, and many buildings and roads would have to be protected by concrete retaining walls. With the lower ebb-tide levels, drastic dredging would become necessary. Wharves and other harbour facilities may need to be rebuilt for the higher range of tide and much rerouting be done of highways with bridges. Large indemnities would be claimed by owners of lands, buildings and water frontages.

Since ice would be trapped in both inlets, and water temperatures thus be lowered, fish breeding may be affected adversely, chiefly due to delayed hatching. Movements of fish may not be disturbed seriously for, although prevented from swimming through the Strait, they could easily pass the Island on the north side.

After due consideration of the problems and effects anticipated with a full causeway, a combination of the third and fourth proposals has been suggested, namely, a causeway with a mile of bridge spans and *also* one or more navigation locks. This would be more expensive than either of these proposals alone but would not seriously alter the tidal currents through the Strait and therefore avoids the damaging effects of higher tides, the cost of protection against them, and the indemnities to property owners. Furthermore, all bridge spans now could be at low level, suitable for the railroad without inclined approaches, for navigation would use the locks.

The whole matter of the highway and rail link between Prince Edward Island and the mainland awaits deeper study and decision which become more urgent with the passing months.

Conclusion

There is just *one* conclusion. The flowing tides provide an answer to that age-old question: What will happen when an irresistible force meets an immovable object? Something *must* go out sideways or upwards—and for the tides it is *up*. So any modern "King Canute" who would attempt to stay the tides or even to modify their movements must reckon on rising flood waters—and the inevitable natural consequences.

"Nae man can tether time nor tide."

—*Robert Burns.*

NOTES FROM OBSERVATORIES

DAVID DUNLAP OBSERVATORY, UNIVERSITY OF TORONTO,
RICHMOND HILL, ONTARIO

The recently modified and improved photoelectric spectrophotometer is being used for an increasing proportion of the observing time of the 74-inch telescope. With this equipment Dr. van den Bergh and two students, William Greig and Richard Henry have embarked upon a new programme of the observation of the distribution of energy in the integrated light of a selected number of globular clusters and elliptical galaxies.

The radio astronomy project shared by the Departments of Astronomy and of Electrical Engineering, heretofore confined to the Electrical Engineering Laboratory at the University and the modest installations at the Observatory, has been greatly strengthened by the provision of more adequate laboratory facilities in the new Galbraith Engineering Building on the Campus and by the completion of a building at the Algonquin Park radio astronomy site which has been provided by the National Research Council for the use of the Toronto group. Current antenna studies now in hand are directed towards plans for installations at the Algonquin Park site.

During the 1960–61 University session nine students of the Mathematics and Physics course were enrolled in the astronomy option of the graduating year. They spent one day each week at the Observatory receiving training in the use of telescopes and other equipment here. All nine were successful in their year, and five of them expect to continue here in graduate studies in astronomy. Among these is Mr. Richard C. Henry who won the Society's Gold Medal for the graduating class in astronomy. In addition to these undergraduates there were eight students enrolled for graduate studies in astronomy during the 1960–61 session.

Dr. van den Bergh and Dr. Wright attended the Christmas meeting of the American Astronomical Society in New York, and Dr. Heard and Dr. Helen Hogg attended the meeting of the Royal Society of Canada in Montreal in June where four papers were presented by members of the staff in addition to the address by Dr. Hogg as President of Section III. Dr. Heard, Dr. van den Bergh and Dr. Hogg attended the June meeting of the American Astronomical Society in Nantucket.

Dr. L. T. Searle who was on leave during 1960–61 has resigned from the Observatory staff to continue research at Mount Wilson and Palomar

Observatories. Dr. K. O. Wright who replaced Dr. Searle here for the 1960–61 session has returned to the Dominion Astrophysical Observatory. Dr. J. D. Fernie from the University of Cape Town has been appointed to the staff as Assistant Professor in Astronomy. Dr. S. van den Bergh has been promoted to Associate Professor.

Among recent visitors to the Observatory were Dr. F. J. Kerr of the Commonwealth Scientific and Industrial Research Organization of Australia, Dr. G. A. Bakos of the Smithsonian Astrophysical Observatory and Professor Charles L. Seeger of Stanford University.

Student assistants employed here this summer on astronomy research projects are, David Auston, Lorne Braun, Miss Sandra Holm and Messrs. John Booker, William Clarke, James Dell, Pim Fitzgerald, William Greig, Richard Henry, David Hogg, Kimmo Innanen, Dom Ng, Olav Poldne and Christopher Purton.

JOHN F. HEARD

VARIABLE STAR NOTES

By Margaret W. Mayall

The American Association of Variable Star Observers, Cambridge, Mass.

213244 *W Cygni.* W Cygni is a semi-regular variable that has been of great interest to observers since its discovery by Gore in 1885. Its visual range is from about 5.0 to 7.6 and the photographic range about one and one half magnitudes fainter. Near minimum the spectrum has been classified as M4e, similar to regular long-period variables, but at other times it is M5 or M6, with no hydrogen emission. In contrast to the more regular long-period variables, the star seems to be bluer at minimum, with hydrogen emission, which disappears when it gets brighter and redder.

The light curve of W Cygni from 1916 through 1960 is plotted in figure 1, from A.A.V.S.O. observations. During the 1930's, most of the observations were from our

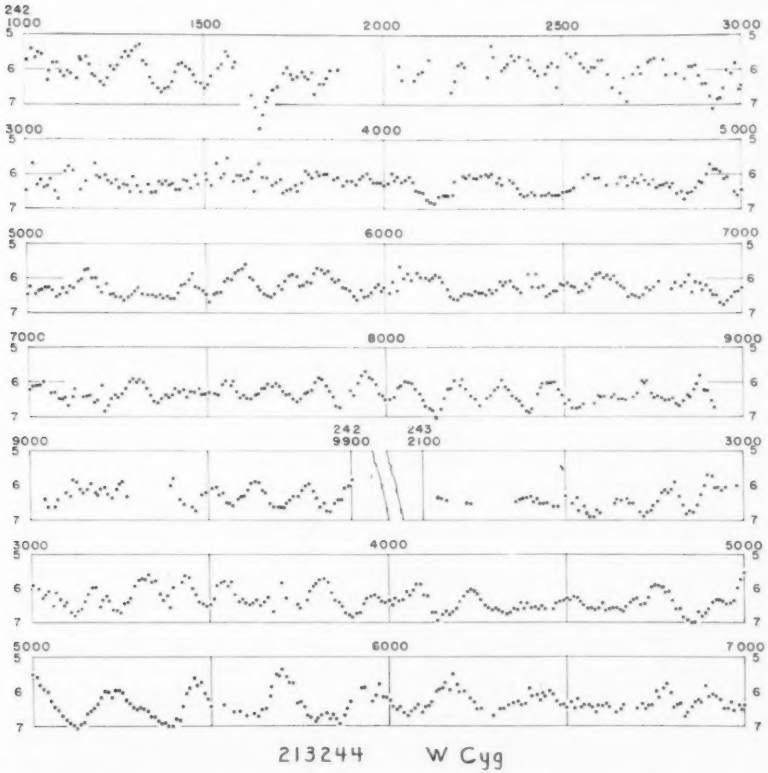


FIG. 1—Light curve of W Cygni, 213244, from 1916 through 1960.

foreign observers. Few reports were received from them in the war years of 1940 to 1946, which accounts for the break in the curve from 2429900 to 2432100. The curve shows a curious combination of quite regular variation in a period of 130 days; fairly regular variation in a period of about 240 days; and times of very little activity, with some indication of a slow change in about 400 days. The 130-day period is evident from J.D. 2427600 to 8600, from 9500 to 9900, and from 2432700 to 3900. The 240-day period shows best from J.D. 2434750 to 6400, and the 400-day between 2423300 and 4800, and from 2436300 to the present.

Many attempts have been made to determine a combination of periods which could account for the variation of W Cygni, but to date no solution has been made which will hold over a long period of time. It has often been called an RV Tauri-type variable, but the chief characteristics of an RV Tauri star, alternating bright and faint minima, do not persist in W Cygni.

The second edition of the *General Catalogue of Variable Stars*, by Kukarkin and Parenago gives the principal elements: Max. = $2430684+130.^{d}85E$, with a secondary oscillation, Max. = $2430573+119.^{d}81E$ superimposed. Unfortunately, the zero epoch occurs in the period for which we have few visual observations, but the two periods do not hold for later observations.

We need long, continuous series of observations of W Cygni by a few good observers, rather than scattered observations by many observers. The ideal would be one or two observations a week by half a dozen observers. The personal equation of each observer could then be determined, and the observations reduced to a common scale.

There are many other bright variables similar to W Cygni which are good for observers in the northern hemisphere, who are limited to small telescopes or binoculars. A selected list of variables was given in these notes in April 1958 (vol. 52, no. 2, p. 89). Many of them are well placed for late summer and early fall observing. A few remarks on some of the most interesting follow.

155947 *X Herculis*. At times varies from 6.3 to 7.4, but during 1960 it was between 6.8 and 7.2 most of the time. Sometimes it shows a period of 75–100 days, and other times the intervals are as long as 150 days. Currently, the range appears to be increasing.

160325 *SX Herculis*. In the 1920's, SX Herculis had nearly a 2 magnitude range and a fairly regular period of around 100 days. For some years the star was nearly constant. The range now is from 8 to about 8.7, and the 100-day period appeared again in 1960. The spectrum of SX Herculis is bluer than many of the other semi-regular variables listed here, and is G3e at maximum.

162542 *g Herculis*. This star is very red (spectrum M6) and has long periods of constant brightness. Oscillations of about 70 days frequently occur, with a long period of about 900 days superposed.

163360 *TX Draconis*. TX has a very small range, usually between 7.5 and 8, with a period around 78 days, superposed on a long variation of 654 days. It is circumpolar and is an interesting star to observe.

181631 *TU Lyrae*. During the early 1950's, TU Lyrae had little variation, but since 1958, the range has increased to about one magnitude, between 10 and 11. The intervals vary from 100 days to about 250.

213753 *RU Cygni*. RU Cygni has had an interesting history since Espin suspected its variability in 1890 (confirmed later by Mrs. Fleming); estimates of its period range from a double period of 396–469 days to a single period of about 235 days. The light curve is distinguished by alternating bright and faint maxima, and bright and faint minima, with a faint maximum usually following a bright minimum. Sometimes the secondary cycle is completely washed out, and the star is nearly constant for the half period. RU Cygni is very red (colour 8) and the range at times is from 7.5 to 9.5.

154428 *R Coronae Borealis.* A light curve of R Coronae Borealis from 1843–1960 was published in these notes just a year ago (vol. 54, no. 4, p. 194). It showed the beginning of the 1960 minimum, the deepest minimum the star has had since 1949. Figure 2 is a detailed plot of that minimum.

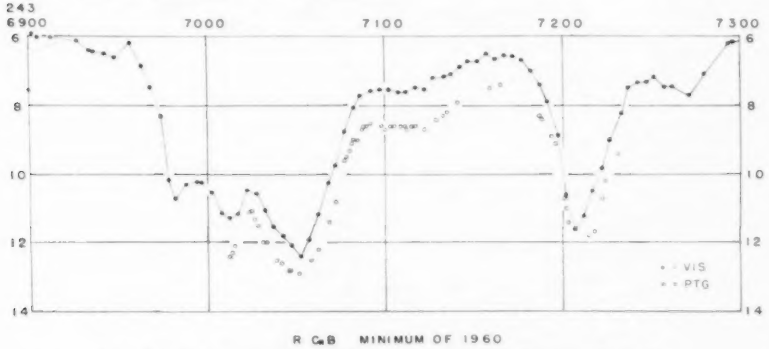


FIG. 2—Light curve of the 1960 minimum of R Coronae Borealis.

The solid dots in the figure are 5-day means of visual observations, and the open circles are photographic observations from Roger Weber of France. Mr. Weber sent the observations to his American colleagues who have observed R CrB visually, with the hope that the comparison of the 2 curves would be of interest. His observations were made with a Berthiot Olor camera 89 mm., f:500 mm. at his private observatory at Mainterne (Eure-et-Loir) France, and cover the period from 18 March to 23 October 1960. The difference between the photographic and visual curves varies from about one half a magnitude at minimum light to a full magnitude at maximum light.

Observations received during March and April 1961: A total of 8,260 was received: 3,590 from 75 observers in March, and 4,670 from 95 observers in April.

Observer	March		April		Observer	March		April	
	Var.	Ests.	Var.	Ests.		Var.	Ests.	Var.	Ests.
Acuna, M.	...	...	5	5	Braune, W.	21	30	24	76
Adams, R. M.	84	133	81	144	Bream, G.	3	3	...	...
Aguirre, V. H.	...	...	2	2	Breckinridge, J.	6	6	...	...
Anderfhuren, E.	...	...	11	27	Buckstaff, R. N.	9	28	13	33
Anderson, Carl	...	...	9	16	Burt, S. E.	3	43	11	39
Anderson, Curtis	22	30	21	33	Caceres, A.	...	...	7	7
Aronowitz, C.	19	19	...	...	Celis S., L.	...	...	11	15
Astudillo, J.	...	...	7	8	Conklin, R.	7	7	...	...
*Axelson, K.	9	9	10	10	Cragg, T. A.	292	375	181	183
Ayala R., H.	18	51	21	48	Debono, I. P.	6	10	...	...
Balassa, T.	...	...	3	3	de Kock, R. P.	109	514	111	426
Barrera S.	...	...	1	1	de la Vega L., R.	...	...	69	206
Bartha, L.	1	1	...	...	de la Vega L., X.	...	...	5	6
Bash, D.	2	2	...	...	Diedrich, DeL.	2	2	1	1
Bicknell, R. H.	...	...	6	6	Diedrich, G.	3	3	3	3
Bradley, D. A.	12	12	...	...	†Engelkemeir, D.	11	23	8	10
Brady, R. F.	46	114	34	60	Erpenstein, O. M.	10	20	10	19

*34^m YZ CMi †17^h 25^m AD Leo

Observations (continued)

Observer	March		April		Observer	March		April	
	Var.	Ests.	Var.	Ests.		Var.	Ests.	Var.	Ests.
Fernald, C. F.	161	277	125	203	Olivarez, J.	...	...	5	5
Fernandes	1	8	2	25	Olmsted, M.	8	13	13	14
Flavin, J.	1	3	1	8	Oravec, E. G.	...	...	156	243
Frogel, J. A.	...	...	4	5	Orchiston, D. W.	22	94	...	...
Garland, G.	...	...	4	4	Ormazabal, M. E.	...	...	2	2
Geerdts, M. T.	...	...	1	1	Ortiz, E.	...	...	12	16
Giffen, C. H.	...	...	1	763	Peltier, L. C.	24	72	37	217
Giordano, P.	...	...	14	18	Pena, J. L. Q.	9	22	9	22
Gonthier, A.	28	73	24	57	Peña V., J.	...	...	9	66
Gonzales, R.	...	...	10	16	Peters, P. J.	...	...	20	20
Goodsell, J. G.	1	1	...	...	Price, R. T.	15	16	28	51
Graham, J. A.	7	8	...	...	Quester, W.	3	7	9	29
Hampton, W. R.	1	1	...	...	Rawstron, G. O.	7	16	9	21
Hartmann, F.	133	146	112	115	Renner, C. J.	70	93	...	...
Hicks, R. L.	5	9	5	17	Rizzo, P. V.	7	15	15	31
Hiett, L.	...	...	6	10	Robinson, L. J.	1	1	1	1
Honda, H.	59	132	64	126	Rosebrugh, D. W.	11	51	11	50
Hurless, C.	14	28	15	48	Ruiz, J. J.	1	176	...	...
Hutchings, N. O.	...	...	4	4	Schilling, M.	...	...	2	2
Judd, D.	2	4	...	...	Severin, M. A.	14	63	...	...
Kelly, F. J.	13	15	12	20	Seavey, H. O.	6	7	6	8
Knowles, J. H.	7	12	5	9	Sharpless, A. P.	28	35	10	12
Lacchini, G. B.	28	120	35	206	Shayler, R. K.	...	...	3	6
Lehmann, P. B.	...	...	23	77	Sherwood, D. A.	11	14	10	15
Lewindon, F.	1	1	1	1	Shinkfield, R. C.	17	49	22	82
Loblay, R.	...	...	3	13	Smith, G. W.	...	...	16	16
Lorenz, E. O.	4	5	10	10	Smith, J. R.	4	4	10	10
Lucas, D.	4	4	6	11	Solano, S.	...	...	11	17
Lynch, J. S.	1	1	2	2	Specht, H. E. M.	...	...	2	11
Martinez G., A. E.	...	..	2	43	Spratt, C.	...	...	5	9
McDonagh, E.	...	...	1	15	Szekely, C.	6	25	...	...
McPherson, C. A.	18	18	31	13	Taboada, D.	139	233	121	162
Mende, R.	8	20	5	23	Thomas, M. A.	1	3	...	...
Miller, R. W.	...	...	37	37	Tompkins, R.	1	2	1	4
Miller, W. A.	21	25	14	14	Travis, N.	...	...	2	2
Montague, A. C.	17	17	28	32	Traynor, F. N.	12	20	15	25
Morgan, F. P.	20	38	18	34	Uribe, C.	...	...	7	8
Mourilhe S., P.	12	19	10	19	van Zyl, L. L.	37	96	36	65
Muniz B., L.	...	...	3	3	Vodrazka, G.	...	...	9	9
Newton, C. S.	1	1	...	...	Wend, R. E.	7	7	...	...
Oberstatter, A.	8	15	12	30	Yamada, T.	12	20	...	...

A.A.V.S.O. Nova Search Report (from George Diedrich, Chairman). Observations of nova search areas were made by the following 18 observers for a total of 343 area-nights reported. Each name is followed by the number of observations made in January and then February, 1961. J. G. Avery—0, 7; Mrs. E. E. Bridgen—20, 17; Mrs. D. Diedrich—6, 13; G. Diedrich—13, 10; Wm. Isherwood, Jr.—30, 12; J. Low—0, 1; D. W. Orchiston—23, 7; Dr. C. J. Phillips—54, 0; R. Price—3, 10; R. C. Shinkfield—3, 2; F. Traynor—18, 8; G. Vodrazka—0, 5; D. Ward—0, 4; W. A. Warren—23, 9; George Wedge—4, 0; K. A. Wells—0, 10; Miss I. K. Williamson—9, 6; and Mrs. K. Zorgo—16, 0.

METEOR NEWS

By Peter M. Millman

National Research Council, Ottawa, Ontario

Meteor Magnitudes Observed in South Africa

One of the problems in meteoric astronomy is to determine the ratio between the numbers of meteors in two magnitude classes, for example the ratio of the number of second magnitude meteors to the number of first magnitude meteors. We can use the symbol r to represent this ratio between successive whole magnitude classes, and in the literature we find values of r ranging all the way from just under 2 up to 4 or higher. Although r is generally taken as constant over a small range of magnitudes, there is good evidence that it varies, the lower values corresponding to the fainter meteor magnitudes.

There is still considerable uncertainty as to the correct value of r for different classes of meteor. I was pleased to receive recently the results of several good series of observations made by J. H. Botham at Johannesburg, South Africa. The observing site was located just outside the city of Johannesburg at an altitude of nearly 6,000 ft. and, when the sky was clear, transparency was good.

The magnitude distributions recorded by Mr. Botham are summarized in Table I. The observational material has been divided into three programmes. Programme A includes the magnitudes of 1484 meteors observed

TABLE I

Meteor Magnitude Distributions

Magnitude	0	1	2	3	4	5	6	7	8	9	10	Total	Mean Mag.
(A) 1951–1958	15	148	243	370	483	201	24					1484	3.2
(B) 1958–1959				3	9	18	41	55	8			134	6.2
(C) 1960				1	1	3	6	19	41	45	8	124	8.1

with the naked eye in the period 1951 to 1958 inclusive. Programme B was carried out in a one-year period during 1958 and 1959. The observations were made with a 2-inch O.G. 6-power moonwatch telescope, having a real field of view 12.5 degrees in diameter, and a limiting magnitude of 9.5. Programme C was carried out during 1960 with a 2.5-inch O.G. telescope equipped with a 27-power eyepiece that gave a real field of

view 2.5 degrees in diameter. The limiting magnitude was 11.2 in good seeing. The field observed was in the zenith, an aluminized flat being mounted in front of the objective, and observations were made in every month except June. A total of 124 meteors was recorded in 38.8 hours of observing time, giving a mean hourly rate of 3.2. This rate is similar to that found by other telescopic meteor observers.

The three magnitude distributions reported here are of particular interest since they are all by the same observer. Using the brighter part of the magnitude range in each case we get $r = 3.0$ for A, $r = 2.9$ for B and $r = 2.4$ for C. This work is a valuable addition to the statistics of meteor magnitudes.

THE ROYAL ASTRONOMICAL SOCIETY OF CANADA

NATIONAL OFFICERS AND COUNCIL FOR 1961

Honorary President—MARC BOYER, D.SC., Deputy Minister of Mines and Technical Surveys
President—PETER M. MILLMAN, PH.D., F.R.S.C., Ottawa
First Vice-President—RUTH J. NORTHCOTT, M.A., Toronto
Second Vice-President—K. O. WRIGHT, PH.D., F.R.S.C., Victoria
National Secretary—J. E. KENNEDY, M.SC., 252 College Street, Toronto 2B
National Treasurer—WILLIAM R. HOSSACK, PH.D.,* 252 College Street, Toronto 2B
Recorder—FREDERIC L. TROYER, Toronto
Librarian—LEONARD A. CHESTER, B.L.S., Toronto

Council—

Elective Members: FRANK J. DEKINDER, Montreal; DAVID A. KEYS, PH.D., D.SC., F.R.S.C., Deep River; ANNE B. UNDERHILL, PH.D., Victoria

Past Presidents: HELEN S. HOGG, PH.D., F.R.S.C., Toronto; R. M. PETRIE, PH.D., F.R.S.C., Victoria

Representatives from Centres:

Calgary Centre: W. H. STILWELL, S. LITCHINSKY (President)
Edmonton Centre: EARL MILTON, FRANKLIN LOEHDE (President)
Halifax Centre: REV. M. W. BURKE-GAFFNEY, S.J., B. W. ALLEN (President)
Hamilton Centre: G. M. VANSICKLE, JAMES A. WINGER (President)
London Centre: WILLIAM WEHLAU, R. W. RICHARDSON (President)
Montreal Centre: C. M. GOOD, E. E. BRIDGEN (President)
Centre Français de Montréal: FLEURANGE LAFOREST, GASTON LEBRUN (President)
Niagara Falls Centre: J. FORBES BOOTH, FRANK A. CAMPBELL (President)
Ottawa Centre: W. L. ORR, IAN HALLIDAY (President)
Quebec Centre: PAUL-H. NADEAU, J. ALFRED DUMONT (President)
Toronto Centre: JOHN F. HEARD, R. R. BROADFOOT (President)
Vancouver Centre: V. J. OKULITCH, J. A. JACOBS (President)
Victoria Centre: K. O. WRIGHT, J. L. CLIMENHAGA (President)
Windsor Centre: HENRY LEE, R. P. NELSON (President)
Winnipeg Centre: R. J. LOCKHART, W. W. WRIGHT (President)

*Deceased

Vol. 55, No. 4 AUGUST 1961 Whole No. 451

Galactic Structure at Optical and Radio Wave-Lengths ..... *Maarten Schmidt* 149
Solar Emission at Ten Centimetre Wave-Length ..... *Arthur E. Covington* 167
The Supernova in NGC 4564 ..... *Sidney van den Bergh* and *R. C. Henry* 173
Tampering With the Tides ..... *F. Keith Dalton* 176

NOTES FROM OBSERVATORIES ..... *John F. Heard* 189

VARIABLE STAR NOTES ..... *Margaret W. Mayall* 191

METEOR NEWS ..... *Peter M. Millman* 195

EDITOR—Ruth J. Northcott

ASSOCIATE EDITORS—C. S. Beals, R. M. Petrie, A. Thomson

COMMUNICATIONS TO THE EDITORS SHOULD BE ADDRESSED TO
David Dunlap Observatory, Richmond Hill, Ontario

The Society publishes this JOURNAL bi-monthly (February, April, June, August, October and December) and the OBSERVER'S HANDBOOK annually. Single copies of the JOURNAL are 75 cents, of the OBSERVER'S HANDBOOK, one dollar.

Membership, which includes the publications, is open to anyone interested in astronomy. Annual dues are $5.00; life membership is $75.00. Applications for membership or publications should be made to THE ROYAL ASTRONOMICAL SOCIETY OF CANADA, 252 COLLEGE STREET, TORONTO 2B, ONTARIO.